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The Chemicals We Get From Potatoes

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The carbohydrates, proteins, and minerals that make potatoes an excellent food for our bodies also furnish excellent nourishment for molds, bacteria, and other microbial forms of life. In the language of the microbiologist, the potato is a good substrate for the growth of micro-organisms. The liquor from boiled potatoes, "potato broth," has long been established as a nutrient medium in experimental microbiological work. That is to say, in culturing, or growing, bacteria and molds in order to identify species, determine numbers, or increase their concentration preparatory to putting the micro-organisms to practical use, potato liquor provides the necessary stimulation for growth.

Potatoes contain about 20 percent solid matter and 80 percent water. Starch, by far the most important solid constituent, accounts for 65 to 75 percent of the potato on the dry basis. Potatoes ordinarily contain little sugar, but the starch can be converted into the fermentable sugars maltose and dextrose.

About 10 percent of the dry matter is protein, much of which is present in soluble form. Free amino acids, the simple building blocks of protein, are also present. A good part of the protein content of the potato, therefore, is in a readily available condition for utilization by micro-organisms. Essential inorganic elements, such as potassium, phosphorus, and magnesium, occur in adequate amounts among the mineral constituents of the potato. Other necessary growth factors are also present.

Large tonnages of potatoes have been fermented to produce ethyl alcohol, the common beverage and industrial alcohol. During periods when grain is scarce or costly, potatoes have been used to great advantage when they were available in sufficient quantity. In 1946, 29 million bushels of potatoes were used by alcohol distilleries. Most of the potato spirits has gone into industrial alcohol; some has appeared in blended whiskies and liqueurs. In 1947, 13.3 percent of the alcohol produced in the United States came from potatoes (compared to 16.5 percent from grain), with ethyl sulfate—a synthetic method starting with petroleum—and molasses serving as raw materials for most of the production.

An attempt was made during the Second World War and immediately afterward to popularize the blended whisky containing potato alcohol. Through the period of hostilities, the production of grain alcohol for beverage purposes was banned because industrial alcohol was sorely needed in the war effort. It is likely that people associated the potato alcohol with the idea of an inferior, temporary war substitute. At any rate, when potable grain alcohol again became available, little or no market remained for potato alcohol in beverages. Europeans have long used potato alcohol in vodka and other liquors. Actually the difference in taste between grain and potato alcohol is negligible.

Butyl alcohol, which is valuable in the formulation of lacquers and in the synthesis of organic chemicals, also is obtained by fermentation of potatoes. We do not know how many potatoes have been used in the fermentation of butyl alcohol, but the quantity has been large since 1946. Late in 1948 the price of fermentation butyl alcohol dropped from 32 cents to 17.5 cents a pound on tank-car lots, largely because millions of bushels of surplus potatoes were available at low cost through the Government's diversion program. The price drop placed fermentation butyl alcohol in direct competition with the synthetic grade, an unusual situation. Eighteen percent of the 35 million bushels of surplus potatoes from the 1947 crop went into the production of ethyl and butyl alcohols. From the 1948 crop, 34 percent of the 133 million bushels acquired by the Government were used in the fermentation of those two alcohols.

IN THEORY IT IS POSSIBLE to produce almost any fermentation product from potatoes. For various reasons, however, it would not be feasible to use potatoes in all fermentations. In some, the non-carbohydrate constituents may interfere with fermentation of the sugar, uncontrollable side fermentations may occur, or insurmountable difficulties may arise in isolation and purification of the desired product.

The Eastern Regional Research Laboratory undertook a study to determine the suitability of cull and surplus potatoes for various fermentations. Early in 1947, P. A. Wells, the director, suggested using potatoes in a novel way in fermentations. He pointed out several advantages of potatoes for this use. Potatoes might be of value in culturing and propagating organisms that produce the amylases (starch-splitting enzymes), which are necessary agents in forming the sugars so that fermentations can proceed. The potato nutrients also would be expected to promote the fermentation of the sugars. Hence, he suggested that the conversion of potato starch to sugars and the fermentation of the sugars to other products might be carried out simultaneously. Chemists and microbiologists joined forces in developing this line of work.

We estimate that if potatoes were carefully graded and only the best grades sold for table use, a supply of subgrade stocks of 50 million bushels or more a year would exist. A fermentation industry based on such a large quantity of raw material would seem entirely feasible. Assurance of a constant supply of raw material is a requisite for the development of any large-scale industrial processing.

The problems associated with utilization of potatoes in industrial fermentations arise from their perishability and the high water content that gives them their great bulk and weight.

Freshly dug potatoes go through a rest period for about 2 months after harvesting. During that time they will not sprout, even at relatively high temperatures. Afterwards, they must be stored in a cool place or treated with a sprout inhibitor to keep them dormant and prevent sprouting. In the Northern States, where there are facilities for storage over the winter, processing of fresh potatoes can be spread over about 8 months of the year. The intermediate crop of potatoes—which is harvested in midsummer and late summer—is stored for only a few months. Practically no early-crop potatoes are stored in the Southern States.

Because potatoes are four-fifths water, they are bulky and heavy to transport and comparatively costly to handle, unload, store, and process at industrial plants. The ideal situation is to have processing plants in the potato area where transportation costs are kept down. It also appears advisable, though, to have facilities for dehydrating potatoes to convert them into stable form. A stockpile of dehydrated potatoes would enable processors to operate the year around through both low- and surplus-production years.

Potatoes have only a low value as raw material for fermentation of ethyl and butyl alcohols, in which they must compete with cheap blackstrap molasses and the synthetic processes. Cuban blackstrap molasses was available in Philadelphia at a cost of only about 4 cents a gallon (in February 1950). At that low cost, the fermentable sugars are worth about 0.6 cent a pound. Potatoes containing 14 percent fermentable carbohydrate would thus be worth only 8.4 cents a hundred pounds, delivered, in competition with blackstrap molasses at 4 cents a gallon. Nevertheless, surplus potatoes costing approximately three times that figure, delivered, were used in Philadelphia in February 1950. Apparently the supply of cheap molasses is inadequate at times.

Ventures in alcohol production from cull and surplus potatoes have failed in Idaho and Maine in the past few years. Because there was little demand for industrial alcohol in the vicinity of each distillery, the output had to be shipped great distances to heavy industries that constituted markets. We believe it is possible, however, that alcohol can be produced successfully in regions of large potato acreages if alcohol comes into common use for supplying automotive power. Maine, Minnesota, North Dakota, and Idaho—potato States far from cheap industrial alcohol—might then find it economical to use alcohol manufactured from locally produced potatoes for blending with gasoline to provide fuel for cars, busses, trucks, and tractors.

Potatoes admittedly are worth only a trifle now in competition with blackstrap molasses in the fermentation of ethyl and butyl alcohols, but research workers are constantly on the alert for new fermentations in which potatoes may have sufficient superiority to command a higher price than their carbohydrate content alone would warrant.

Minor differences in nutrients and traces of essential constituents present sometimes mean a lot in fermentations. For example, lactose (milk sugar) is used instead of the much cheaper sucrose (cane or beet sugar) in the *Penicillium notatum* fermentation to produce penicillin. Lactose has the same chemical elements and molecular weight as sucrose, but it gives a better yield of penicillin.

Although blackstrap molasses costs little as a fermentation material, it has so far been unacceptable in its impure state for some fermentations, such as the production of lactic and citric acids. We hope to uncover practical fermentations in which cull and surplus potatoes are an economical raw material.

The production of lactic acid, which was first studied, illustrates what might possibly be done with other fermentations.

In the lactic acid fermentation, clean potatoes are first ground and cooked. The next step is to convert the starch to sugars by hydrolysis, a process in which the starch takes up water and breaks down into the sugars maltose and dextrose with dextrins as the intermediate products.

Hydrolysis of the starch is necessary in order to convert the relatively large starch molecules of complicated structure into simple, readily soluble sugar molecules that will undergo fermentation. The hydrolysis of starch is catalyzed by the addition of mineral acids, such as hydrochloric or sulfuric acid, or by the presence of enzymes (biological catalysts). Amylases (starch-splitting enzymes) produced by strains of the mold *Aspergillus niger* were employed in the starch conversion. Investigations at the Northern Regional Research Laboratory, at Joseph E. Seagrams & Sons, Inc., and at U. S. Industrial Chemicals, Inc., have shown that these strains of *A. niger* can produce amylases when grown in submerged culture on distillery wastes. It was found at the Eastern Laboratory that potato mash could also serve as an excellent nutrient medium for culturing the mold strains in the production of the enzymes. After growth for 5 or 6 days on a potato mash that contained 5 percent potato solids and 1.5 percent calcium carbonate, the mold culture was ready for use in saccharifying potatoes (converting their starch to sugar).

After the saccharification of the potatoes had been allowed to proceed for a while, a culture of a bacterium capable of producing lactic acid from dextrose (*Lactobacillus delbrueckii* or *Lactobacillus pentosus*) was added. An excess of calcium carbonate was maintained in the mash to neutralize the acid as it was formed during the fermentation. Otherwise, the acidity would stop the growth of the bacteria. Three to four days were required to complete the fermentation. By the process, 80 to 90 percent of the starch originally present in the potato was converted to lactic acid.

A manufacturer of lactic acid—Clinton Foods, Incorporated, of Clinton, Iowa—has produced several commercial-scale batches of the acid from potatoes by the process tested at the Eastern Laboratory. The company had no unusual difficulties in carrying out the fermentation.

A RESEARCH WORKER IN INDUSTRY—Dr. O. K. Sebek, then in the employ of a firm of distillers—has found that *l*–2,3-butanediol can be produced by the fermentation of white potatoes with *Bacillus polymyxa*.

l–2,3-Butanediol is an alcohol that is potentially valuable as a solvent, reactant, and antifreeze. To produce it, the potatoes were diced, macerated in a food blender, and diluted with twice their weight of water. The mash was heated to 158° F., and 1 percent of malt (based on the potato weight) was added to thin it down to a consistency that could be easily stirred. After the mash had been heated to boiling to cook the starch, it was cooled, 1 to 1.5 percent of calcium carbonate was added, and fermentation was started by inoculation with *B. polymyxa*. This bacterium produces its own amylase and no additional saccharifying enzyme is needed.

Investigations by E. A. Weaver at the Eastern Laboratory in 1949 indicate that amylases can be produced in high yields by certain strains of the mold *Aspergillus niger* when grown submerged on whole-potato media. Growth is very rapid, but the amylases are held within the young cells. They can be released, however, by breaking down the cell walls. By including this process of comminution, high yields are obtained in 15 to 18 hours fermentation time, whereas 4 to 5 days are required to reach high potencies if the amylases have to diffuse through the cell walls. If the excellent laboratory results can be reproduced on a commercial scale, potatoes may become a cheap source of amylases.

OTHER PRODUCTS that might be produced by fermentation of potatoes include glycerin and five acids—citric, gluconic, fumaric, itaconic, and kojic.

Potatoes might also be used as a culture medium in other microbiological processes, as, for example, the production of antibiotics by molds, actinomycetes (organisms having characteristics intermediate between bacteria and molds), and bacteria.

Dr. Harry Humfeld, of the Western Laboratory, has shown that the mushroom fungus *Agaricus campestris* produces the mushroom flavor when grown submerged. Potatoes might possibly be used as a food for this organism.

Preliminary results indicate that potato mash saccharified with mold amylase can be used for the production of feed yeast. As yeasts multiply, they convert the carbohydrate and other constituents of the potato into protein. In order to produce a high-protein yeast and increase the amount of protein synthesized, it is necessary to provide additional nitrogen. The nitrogen comes from both the soluble form present in the potato and from inexpensive sources, such as ammonia, ammonium salts, or urea. The protein that is produced is obtained by harvesting the yeast cells.

It should be borne in mind that, with the exception of the ethyl and butyl alcohol fermentations, much that has been said about fermentations of potatoes is conjecture. Several of these potential fermentations have given promising results in preliminary laboratory work, but it will take many months to determine their commercial practicability.

So it appears that a well-developed pattern for utilization of substandard and surplus potatoes must include their use in the fermentation industry and various microbiological processes. Starch production, flour production, and livestock feeding all have their proper places in the economy of the potato industry, but those old-established methods of utilization must be supplemented by industrial fermentations if all off-grade potatoes are to be used. The potato has long been known as an excellent substrate for microorganisms. The challenge to research is to find practical fermentations based on potatoes in which their use is economical. A solution to this problem would not only be a boon to agriculture but a bulwark in national defense. Particularly during periods when grain and molasses are scarce and potatoes are abundant, it is important to have information available on methods of converting potatoes into needed chemicals and other products of microbiological reactions.

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